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CRATERS FORMED BY SMALL EXPLOSIONS IN DRY SAND

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U. S. Army Engineer Waterways Experiment Station
CORPS OF ENGINEERS
Vicksburg, Mississippi

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CRATERS FORMED BY SMALL EXPLOSIONS IN DRY SAND

MISCELLANEOUS PAPER NO. 2-524

September 1962

U. S. Army Engineer Waterways Experiment Station

CORPS OF ENGINEERS

Vicksburg, Mississippi

Preface

In 1955 the U. S. Army Engineer Waterways Experiment Station completed a study entitled "Effects of Explosions in Shallow Water" during which it was desirable to detonate twenty 4-lb charges at reduced charge positions varying from 1.0 to -0.26 over dry sand to compare the results with those of similarly placed underwater shots. This paper presents the results of the dry sand tests.

The investigation was conducted under the general supervision of Mr. E. P. Fortson, Jr., Chief of the Hydraulics Division, and Mr. F. R. Brown, Chief of the Hydrodynamics Branch, and under the direct supervision of Mr. G. L. Arbuthnot, Jr., Chief, Special Investigations Section, and Mr. J. N. Strange. This paper was prepared by Mr. R. A. Sager.

Col. A. P. Rollins, Jr., CE, Col. Edmund H. Lang, CE, and Col. Alex G. Sutton, Jr., CE, were Directors of the Waterways Experiment Station during the course of this investigation and the preparation and publication of this report. Mr. J. B. Tiffany was Technical Director.

Contents

Notations

A_A Apparent crater cross-sectional area, ft^2

D_A Apparent crater diameter, ft

H_A Apparent crater depth, ft

H_L Apparent crater lip height, ft

V_A Apparent crater volume, ft^3

W Weight of charge, lb TNT

Z Location of center of gravity of charge with reference to ground surface, ft

λ_c Reduced charge position, $Z/W^{1/3}$, $ft/lb^{1/3}$

CRATERS FORMED BY SMALL EXPLOSIONS IN DRY SAND

Introduction

1. In 1955, the Waterways Experiment Station (WES) completed a study of the effects of explosions in shallow water.* During the course of this study, a great number of charges of various weights were detonated in shallow water over a sand bottom. As the shallow-water explosion effects program progressed, it became desirable to compare cratering data from charges fired in a water layer with data from charges fired at equivalent height of burst over dry media. A series of cratering shots were fired over, on, and within a dry-sand media in order to make possible this comparison. Such a comparison was made in the shallow-water report; however, the detailed results of the abbreviated test series in dry sand were not reported therein. It is therefore the purpose of this paper to (a) describe the tests and (b) report the results and conclusions that are appropriate when the dry-sand cratering data are treated separately.

Experimental Conditions and Procedures

Test area

2. The test shots were detonated at the WES Big Black test site located approximately 10 miles southeast of Vicksburg, Mississippi. The charges were fired in a sand pit 10 by 10 by 2-1/2 ft deep. The sand used to fill the test pit was well graded, as is evident from the grain-size distribution curve shown in fig. 1. Results of seven moisture-content determinations, taken before, during, and immediately after the test program, indicated an average moisture content of 6% (by weight).

3. Many of the test shots were detonated in approximately the same location within the sand pit; therefore, it was necessary to remold and recompact the sand after each shot. Particular care was taken to ensure that the density of the sand was approximately the same for each shot.

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* U. S. Army Engineer Waterway Experiment Station, CE, Effects of Explosions in Shallow Water (U), Technical Report No. 2-406 (CONFIDENTIAL), Vicksburg, Miss., April 1955.
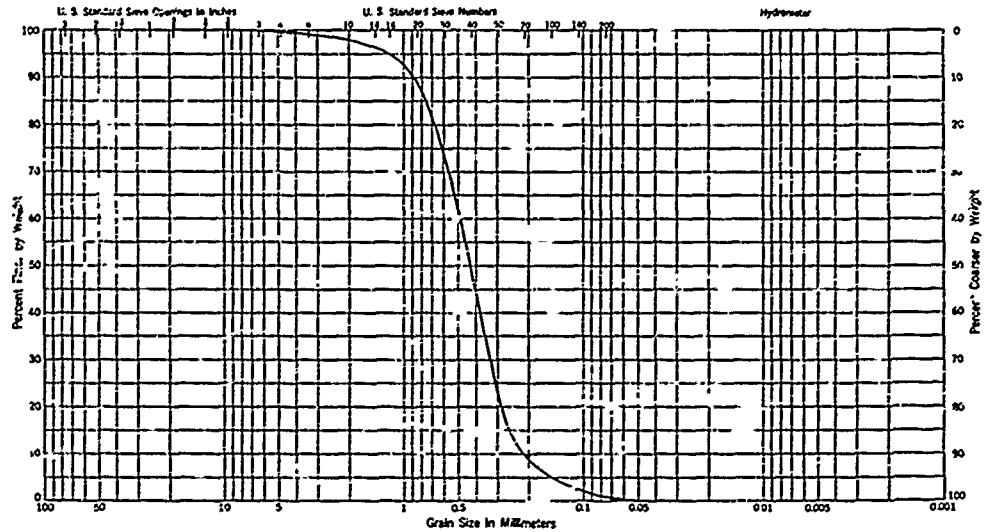
Fig. 1. Mechanical analysis curve for crater medium

Fig. 2. Typical 4-lb TNT charge geometry

Charge

4. The test charges used weighed 4 lb each and were formed from four standard Corps of Engineers 1-lb TNT demolition blocks. All blocks were placed with the long side in a vertical position as shown in fig. 2. The charge depth was referenced to the center of gravity of the charge. Positive values of charge depth (Z and λ_c) denote that the charges were placed above ground surface; negative values denote that charges were placed underground. Dimensions of each 4-lb charge were 3-3/4 by 3-3/4 by 7 in.

Crater measurements

    5. The measurements of all crater parameters were accomplished by using the square framework shown in fig. 3 as a reference frame. It was
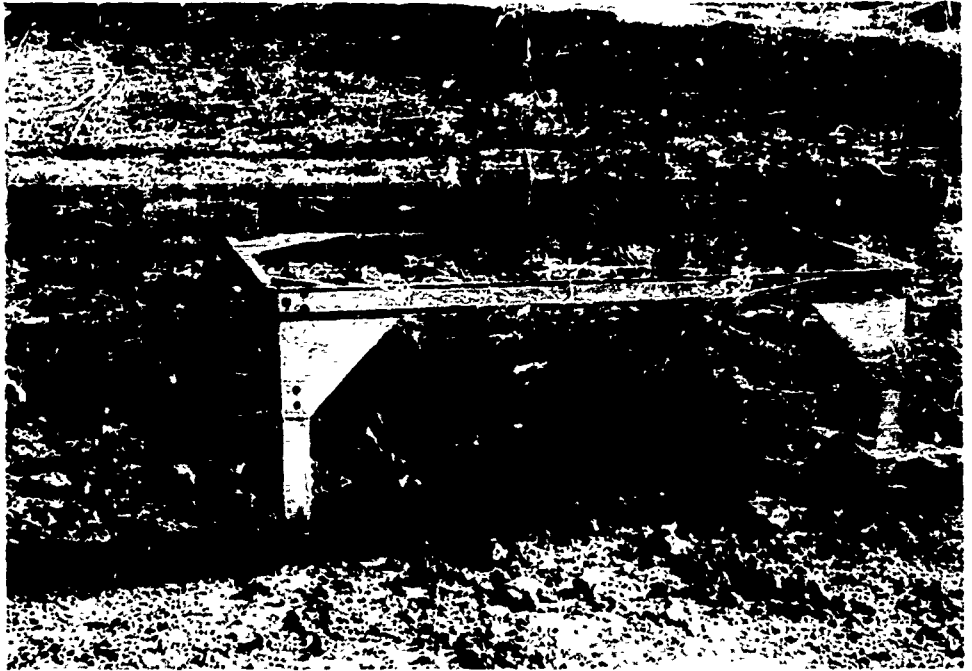

Fig. 3. Framework for surveying crater. (Photo taken
during another test program in soil)

centered over the crater area and then leveled by means of leveling screws attached to each supporting leg. The framework then provided both horizontal and vertical control from which crater soundings and horizontal dimensions were obtained. Although the craters were quite symmetrical (no charge-shape effect was noted), at least two cross-sectional profiles were obtained for each crater. Crater volumes were computed by revolving the resulting average crater profiles about the vertical axis through ground zero.

Test Results

    6. The average crater dimensions of the twenty 4-lb test shots are summarized in table 1. Two shots were detonated at each of 10 different reduced charge positions with a maximum λ_c of 1.0 and a minimum of -0.25

Table 1

Summary of Average Apparent Crater Dimensions

| | Charge Position | | Crater Results | | | | |
Test No.	Z^*	λ_c^*	Diameter D_A	Depth H_A	Lip Height H_L	Area A_A	Volume V_A
683	1.59	1.0	3.50	0.19	0	0.43	0.84
684	1.59	1.0	3.22	0.13	0.03	0.28	0.55
Average			3.36	0.16	0.015	0.355	0.695
Deviation, %			4	19	100	21	20
685	1.27	0.8	3.38	0.18	0.04	0.34	0.58
686	1.27	0.8	3.31	0.13	0.03	0.31	0.64
Average			3.345	0.155	0.035	0.325	0.61
Deviation, %			1	16	14	4.6	4.9
687	0.95	0.6	3.37	0.13	0.04	0.32	0.69
688	0.95	0.6	3.35	0.14	0.04	0.35	0.72
Average			3.36	0.135	0.04	0.335	0.705
Deviation, %			0.2	3	0	4	2.1
689	0.64	0.4	3.41	0.20	0.02	0.46	0.87
690	0.64	0.4	3.38	0.19	0.02	0.46	0.92
Average			3.395	0.195	0.02	0.46	0.895
Deviation, %			0.4	2.5	0	0	2.6
691	0.48	0.3	3.32	0.26	0.04	0.56	1.07
692	0.48	0.3	3.39	0.22	0.05	0.51	1.02
Average			3.355	0.24	0.045	0.535	1.045
Deviation, %			0.7	4	11	4.6	2
693	0.32	0.2	3.32	0.33	0.08	0.81	1.77
694	0.32	0.2	3.40	0.32	0.07	0.81	1.66
Average			3.36	0.325	0.075	0.81	1.715
Deviation, %			1	1.5	6	0	3
695	0.16	0.1	4.29	0.49	0.08	1.33	4.10
696	0.16	0.1	4.19	0.57	0.10	1.59	3.78
Average			4.24	0.53	0.09	1.46	3.94
Deviation, %			1.1	7	11	8	4
697	0	0	5.23	0.87	0.08	2.54	7.27
698	0	0	5.02	0.81	0.15	2.52	7.10
Average			5.125	0.84	0.115	2.53	7.185
Deviation, %			2	3.5	29	0.4	1.1
699	-0.21	-0.13	5.95	1.22	0.24	4.07	12.90
700	-0.21	-0.13	6.16	1.20	0.24	4.29	14.21
Average			6.055	1.21	0.24	4.18	13.555
Deviation, %			1.7	0.8	0	2	4
701	-0.42	-0.26	6.84	1.40	0.26	5.62	20.97
702	-0.42	-0.26	6.86	1.39	0.29	5.56	20.47
Average			6.85	1.395	0.275	5.59	20.72
Deviation, %			0.1	0.3	5	0.5	1.2

* Positive values of Z and λ_c denote charges that were placed above ground surface; negative values denote charges that were placed underground.

An examination of the results of each pair of shots indicates that the data were consistent. The deviations for each crater parameter are shown in table 1.

7. All shots in which the charges were located above the ground surface resulted in symmetrical craters with relatively flat bottoms and gently r.sing side slopes as shown in fig. 4a. The shots with charges located at the ground surface or below resulted in symmetrical craters of steeper side slopes as shown in fig. 4b.
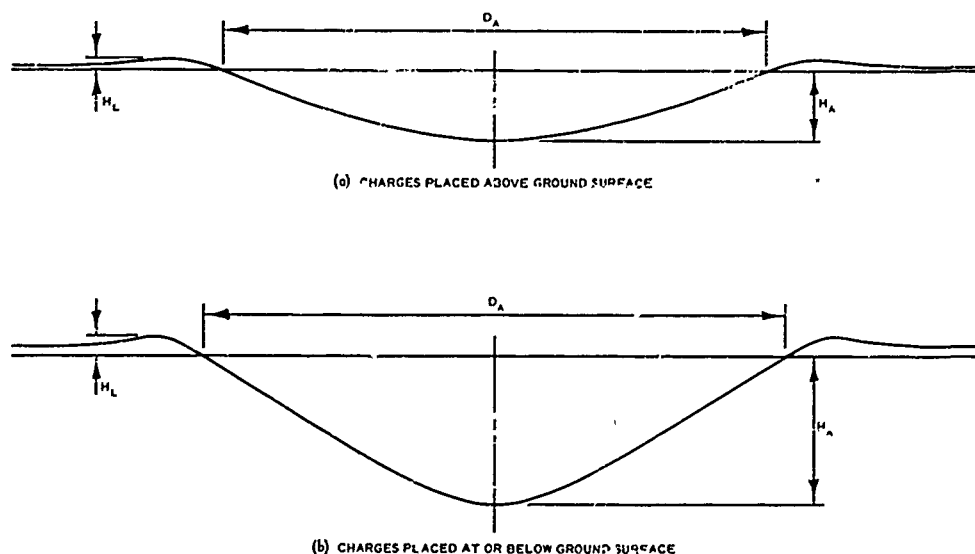

(a) CHARGES PLACED ABOVE GROUND SURFACE

(b) CHARGES PLACED AT OR BELOW GROUND SURFACE

Fig. 4. Typical apparent crater geometries

8. As can be seen in table 1, the apparent crater diameters (D_A) for all shots fired at a λ_c of 0.2 and above were consistent, ranging from 3.22 to 3.50. Below a λ_c of 0.2 the crater diameter increased with decreasing values of λ_c through the deepest charge position investigated $(\lambda_c = -0.26)$.

9. An increase in charge height above $\lambda_c = 0.6$ influenced the apparent crater depth (H_A) very little. From a λ_c of 0.6 to 0.2 the effect of λ_c on the crater depth became more pronounced, and below $\lambda_c = 0.2$ the crater depth increased significantly with decreasing values of λ_c (see table 1). Fig. 5 shows a plot of the cube-root-of-charge-weight scaling of the crater diameter and depth versus reduced charge position.

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Examination of both the depth and the diameter curves indicates that
charges were not placed deep enough to define the maximum apparent crater
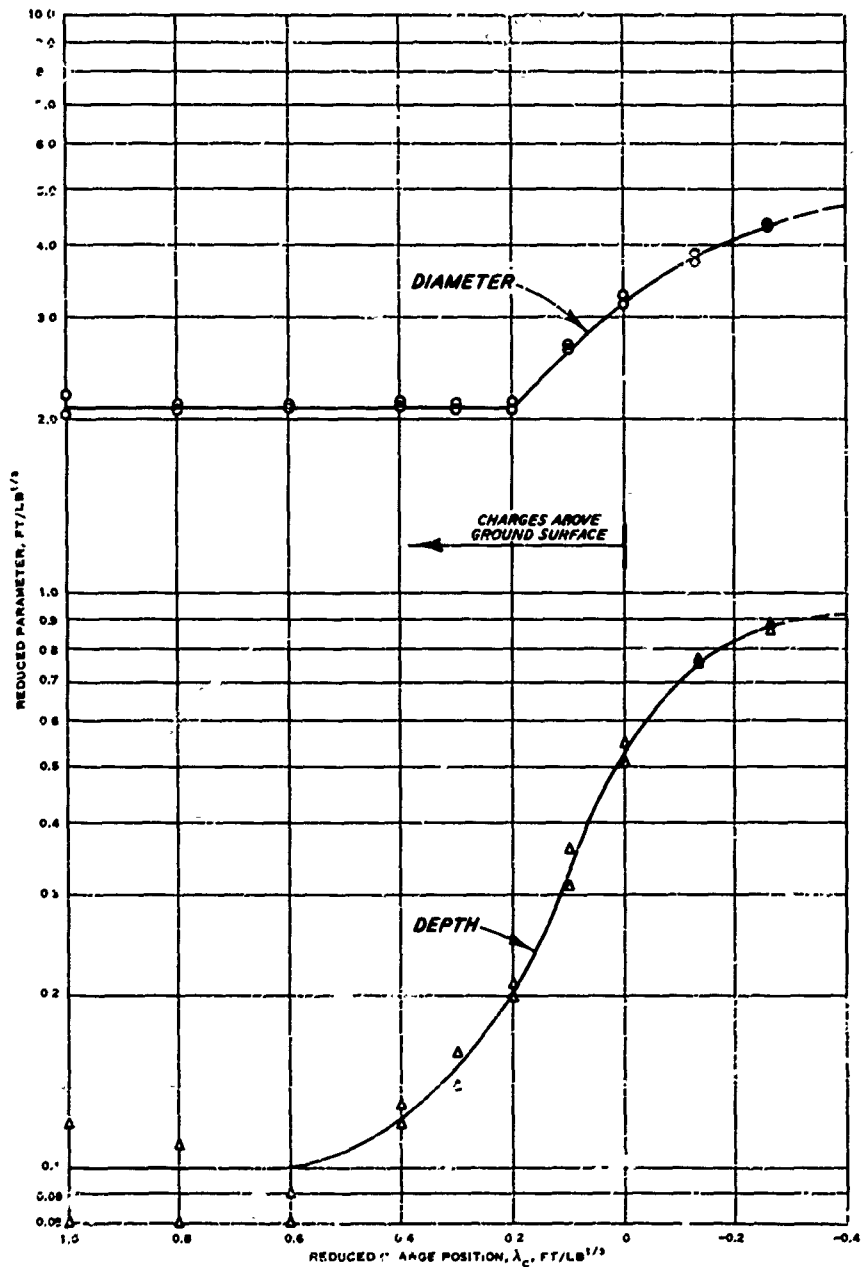depth or diameter.

Fig. 5. Reduced diameter and depth versus reduced charge position

10. Fig. 6 is a plot of the cube-root-of-charge-weight scaling of the crater area and volume versus reduced charge position. An examination of both curves indicates that increases in λ_c above 0.4 had little effect on the area or volume. Both parameters are greatly affected as the charge position approaches and goes below the ground surface, increasing significantly with decreasing values of λ_c. Extension of both curves indicates that the optimum charge position (i.e. the charge position resulting in the maximum crater area or volume) is considerably below $\lambda_c = -0.26$.
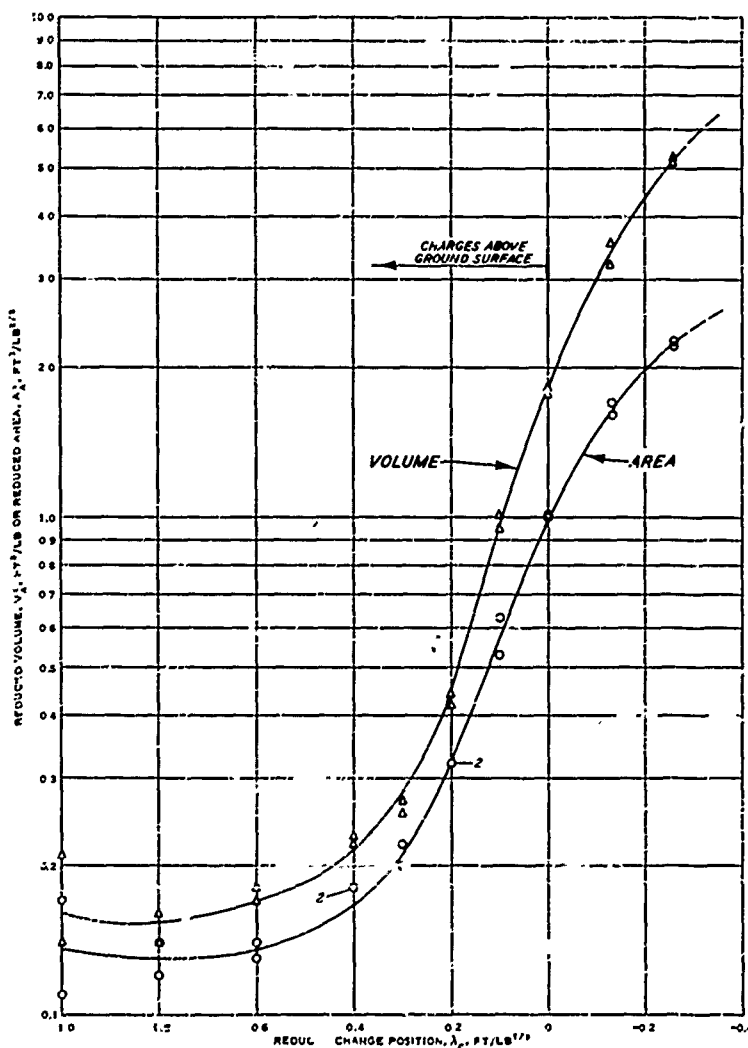

Fig. 6. Reduced area and volume versus reduced charge position

11. A plot of diameter over depth (D_A/H_A) versus reduced charge position is shown in fig. 7 and indicates that little scatter of data was experienced for charge positions where λ_c was less than 0.6. On the other hand, a plot of lip height over depth (H_L/H_A) versus reduced charge position (fig. 8) shows very erratic data. This can probably be explained by the fact that all the lip heights were quite small, and little changes in the lip heights, due to wind, particle-size distribution of the crater medium, inaccuracies in measuring, etc., had a pronounced effect on the results.
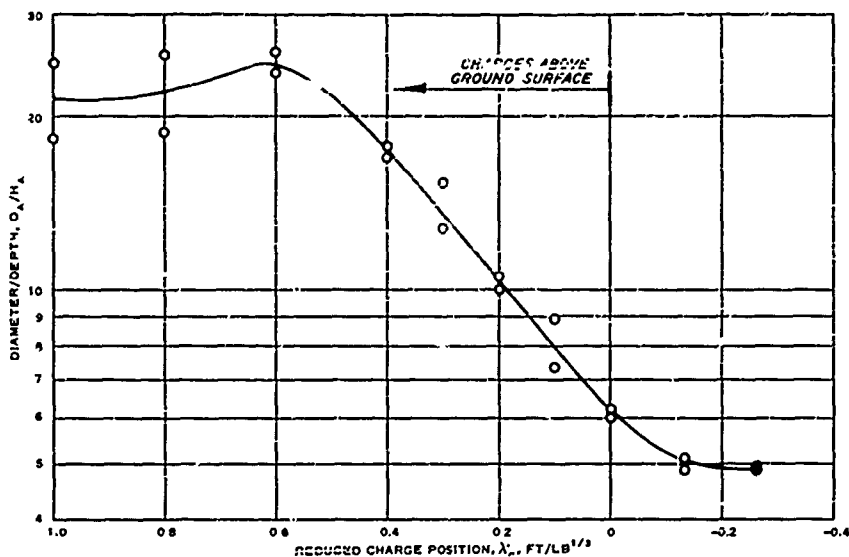

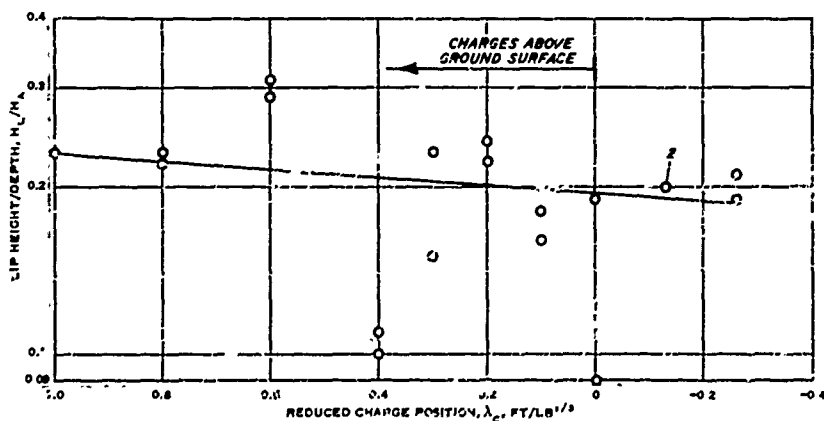Fig. 7. Diameter/depth versus reduced charge position

Fig. 8. Lip height/depth versus reduced charge position

Conclusions

12. From the results of the tests described herein, the following conclusions appear warranted:

    a. For λ_c values of 0.2 and greater, apparent crater diameters are consistent and ranged in this study from 3.22 to 3.50. Below a λ_c of 0.2, crater diameter increases with decreasing λ_c.

    b. Increases in λ_c above 0.6 influence crater depth very little. In this region of charge positions, the crate ing action is mainly a result of the scouring action of the airblast wave. For values of λ_c greater than 1.0, obviously a charge position will soon be reached where no apparent crater will form. For λ_c values of less than 0.6, crater depth increases with decreasing λ_c.

    c. Increases in λ_c above 0.4 have little effect on crater area and volume. Below $\lambda_c = 0.4$, both area and volume increase with decreasing λ_c.

    d. Optimum charge position to produce maximum crater area and volume is below $\lambda_c = -0.26$.